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Operation of Charge Controllers in Distributed Multi Source (Solar and Wind) Hybrid Power Generating Systems

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In large PV hybrid power systems, battery management is critical due to the continuous operation of the power system, the limited power available for temperature control in the battery room, and the high cost of maintenance.Charge controllers are required in solar or wind power generating systems where electrical energy storage is required in these systems. Optimal charging is required in order to improve the performance and life of the batteries. The charge controllers are used for optimal charging of the entire system. The different types of charge controllers, terminologies, set points and importance of hybrid system are explained in this paper. The shunt and series type charge controller's current and voltage regulations are shown and battery current and voltage characteristics according to the source availability and load applied are also shown for the understanding.The studies of a system of the three sources (Solar, wind and diesel generator) includes than it in practice to optimize performance by 35% by optimal charging of battery using charge controller.

Keywords *Charge controller, Shunt type controller, Series type controller*

1.0 INTRODUCTION

A charge controller is one of functional and reliable major components in renewable energy systems. A good, solid and reliable charge controller is a key component of any battery charging system to achieve low cost and the benefit that user can get from it. The main function of a charge controller in a renewable energy system is to regulate the voltage and current from sources into a rechargeable battery. The minimum function of a charge controller is to disconnect the source when the battery is fully charged and keep the battery fully charged without damage [1]. A charge controller is important to prevent battery overcharging, excessive discharging, reverse current flow at night and to protect the life of the batteries in a renewable energy system. A power electronics circuit is used in a charge controller to get highest efficiency, availability and reliability. The use of power electronics circuits such as various dc to dc converters topologies like buck converter, boost converter, buck-boost converter and others converter topology as power conditioning circuitry to provide a desired current to charge battery effectively.

A charge controller is an electronic circuit which monitors the charge in and out of the battery and based on a set of voltage thresholds, regulates the current flow in order to limit overcharge and over discharge [2]. Two basic methods, called interrupting charging and constant voltage charging are used. Interrupting charging is also known as on/off charging and constant voltage charging is also known as constant potential

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charging. Controllers are generally either shunt or series type configurations. As a battery approaches full charge, a shunt controller will short circuit and a series controller will open circuit the source to reduce the charging current applied to the battery. A charge controller set point is a battery condition, commonly the voltage, at which a charge controller performs regulation or switching functions. Set points are associated with either charge regulation or load control. Charge controller set points define the range of permissible battery and system voltages. The set points greatly affect battery performance, life and load availability. Optimal charge regulation set-points ensure that the battery is maintained at the highest possible state of charge without over charging and over a range of conditions. Two charge regulation set points regulate the charging function.

PV Array Model

Various equivalent circuit models of a PV cell have been proposed [4-6]. For obtaining high power, numerous PV cells are connected in series and parallel circuits on a panel, which is a PV module. A PV array is defined as a group of several modules electrically connected in series-parallel combinations to generate the required current and voltage. Behavior of a PV array with NS × NP modules may be described by equation shown below. Parameters for the PV module model may be obtained from manufacturer's data sheet in part and by some deduction methods in part [7].

$$\mathrm{I}_A = N_p I_{SC} - N_P I_0 (\exp\left[\frac{V_A + I_A R_S}{n N_S V_T}\right] - 1) \qquad \ldots(1)$$

Where I_A = output current of PV array [A]

I_{SC} = short circuit current of PV module [A]

I_0 = diode saturation current [A]

V_A = terminal voltage of PV array [V]

R_S = series resistance [Ω]

n = ideal constant of diode (1~2)

V_T = thermal potential of PV module [V]

Battery Model

Battery model can usually be divided into experimental model, electrochemical model and equivalent circuit model. The equivalent circuit model is most suitable for dynamic simulation. Based on Shepherd battery model, reference [8] presents a generic battery model for dynamic simulation, which assumes that the battery is composed of a controlled-voltage source and a series resistance. This generic battery model considers the state of charge (SOC) as the only state variable.

The expression of the controlled voltage source is

$$E = E_o - K\frac{Q}{Q - \int i_b dt} + Aexp(-B.\int i_b dt \qquad \ldots.(2)$$

Where, Eh is no-load voltage (V); Eo is battery constant voltage (V); K is polarization voltage (V); Q is battery capacity (Ah); A is exponential zone amplitude (V); B is exponential zone time constant inverse (Ah- 1).

2.0 CHARGE CONTROLLER

The charge controller is a DC to Dc converter whose main function is to control the current flow from the renewable energy sources with the purpose of charging batteries [9]. Most of these devices can maintain the maximum charge of the battery without over charging or over discharging the batteries. The main functions of a charge controller are:

Overcharge protection: The purpose is to prevent the damage in the batteries when they are charged and the sources still supplies energy. This protection interrupts or restricts the current flow from the sources to the batteries and regulates the battery voltage.

Over discharge protection: The purpose is to prevent the damage in the batteries when they are discharged below the point of minimum discharge. The charge controller disconnects the batteries or stops the current flow from the batteries to the load to prevent batteries damage.

3.0 CHARGE CONTROLLER TERMINOLOGY

Charge regulation is the primary function of a charge controller and this issue is related to battery performance and life. The purpose of a charge controller is to supply power to the battery in a manner to fully recharge the battery without overcharging. Limiting the source current to a battery in a system may be accomplished by many methods. The most popular method is battery voltage sensing, however other methods such as amp hour integration are also employed. While the specific regulation or algorithm varies among charge controllers, all have basic parameters and characteristics.

4.0 CHARGE CONTROLLER SET POINTS

The battery voltage levels at which a charge controller performs control or switching functions are called the controller set points. Four basic control set points are defined for most charge controllers that have battery overcharge and over discharge protection features. The voltage regulation (VR) and the array reconnect voltage (AVR) refer to the voltage set points at which the array is connected and disconnected from the battery. The low voltage load disconnect (LVD) and low reconnect voltage (LRV) refer to the voltage set points at which the load is disconnected from the battery to prevent over discharge [11-12]. These set points are shown in Figure 1.

Voltage Regulation set point: The voltage regulation set point is one of the key specifications for charge controllers. The voltage regulation set point is defined as the maximum voltage that the charge controller allows the battery to reach, limiting the overcharge of the battery. Once the controller senses that the battery reaches the voltage regulation set point, the controller will either discontinue battery charging or being to regulate the amount of current delivered to the battery. Proper selection of the voltage regulation set point may depend on many factors, including the specific battery chemistry and design, sizes of the load and array in case of solar photovoltaic array with respect to the battery, operating temperatures, and electrolyte loss considerations.

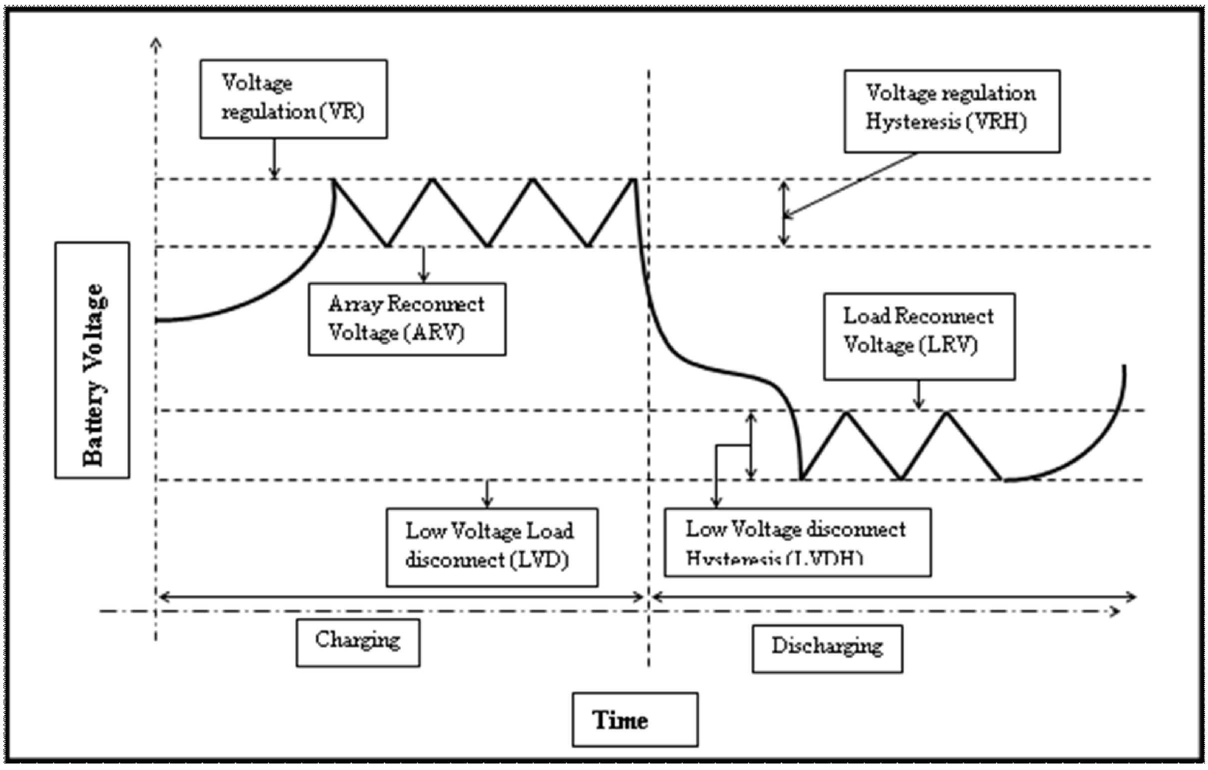

FIG. 1 CHARGE CONTROLLER SET POINTS FOR VOLTAGE REGULATION

Array reconnect voltage set point: In interrupting type controllers, once the array is disconnected at the voltage regulation set point, the battery voltage will begin to decrease. The rate at which the battery voltage decreases depends on many factors, including the charge rate prior to disconnect, and the discharge rate dictated by the electrical load. If the charge and discharge rates are high, the battery voltage will decrease at a greater rate than if these rates are lower. When the battery voltage decreases to a predefined voltage, the array is again reconnected to the battery to resume charging. This voltage at which the array is reconnected is called as the array reconnect voltage set point.

Voltage Regulation Hysteresis (VRH): The voltage span or difference between the voltage regulation set point and array reconnect voltage is called as the voltage regulation hysteresis. The VRH is a major factor which determines the effectiveness of battery recharging for interrupting type controllers. If the hysteresis is too great, the source current remains disconnected for long periods, effectively lowering the source energy utilization and making it very difficult to fully recharge the battery. If the hysteresis is too small, the source will on and off rapidly, perhaps damaging controllers which uses electro-mechanical switching elements. The designer must carefully determine the hysteresis values based on the system charge and discharge rates and the charging requirements of the particular battery.

Low Voltage Load Disconnect (LVD) set point: Over discharging the battery can shorten its operating life. If battery voltage drops too low certain non-essential loads can be disconnected from the battery to prevent further discharge. This can be done using a low voltage load disconnect device connected between the battery and non-essential loads. The LVD is either a relay or a solid state switch that interrupts the current from the battery to the load, and is included as part of most controller designs. In some cases, the low voltage load disconnect unit may be separate unit from the main charge controller. The low voltage load disconnect set point is the voltage at which the load is disconnected from the battery to prevent over discharge. The LVD set point defines the actual allowable maximum depth of discharge and available capacity of the battery. The available capacity must be carefully estimated and sizing process using the actual depth of discharge dictated by the LVD set point. The proper LVD set point will maintain a healthy battery while providing the maximum battery capacity and load availability. To determine the proper load disconnect voltage, the designer must consider the rate at which the battery is discharged. Because the battery voltage is affected by the rate of discharge, a lower load disconnect voltage set point is needed for high discharge rates to achieve the same depth of discharge limit. To properly specify the LVD set point, the designer must know how the battery voltage is affected at different states of charge and discharge rates. In a few designs, current compensation may be included in the LVD circuitry to lower the LVD set point with increasing discharge rates to effectively keep a consistent depth of discharge limit at which the LVD occurs.

Load Reconnect Voltage (LRV) Set point: The battery voltage at which a controller allows the load to be reconnected to the battery is called the load reconnect voltage. After the controller disconnects the load from the battery at the LVD set point, the battery voltage rises to its open circuit voltage. When additional charge is provided by the source, the battery voltage rises even more. At some point, the controller senses that the battery voltage and state of charge are high enough to reconnect the load, called the load reconnect voltage set point. The selection of load reconnect set point should be high enough to ensure that the battery has been somewhat recharged, while not to sacrifice load availability by allowing the loads to be disconnected too long.

Low Voltage Load Disconnect Hysteresis (LVDH): The voltage span or difference between the LVD set point and the load reconnect voltage is called the low voltage load disconnect hysteresis. If the LVDH is too small, the load may cycle on and off rapidly at low battery state of charge (SOC), possibly damaging the load or controller, and extending the time it takes to fully charge the battery. With a large LVDH, the battery health may be improved due to reduced battery cycling, but with a reduction in load availability. The proper LVDH selection for a given system will depend on load availability requirements, battery chemistry and size and the load current.

5.0 CHARGE CONTROLLER CONFIGURATIONS

Controllers are generally built in either shunt or series type configurations. As a battery approaches full charge, a shunt controller will short circuit or series controller will open circuit the source to reduce the charging current applied to the battery.

5.1 Shunt type Controllers

Shunt Interrupting (On/Off): This method diverts the source energy to a parallel path when the battery reaches the full charge voltage regulation (VR) or charge termination set point. Charging is then resumed once battery voltage falls below the voltage regulation reconnect (VRR) or charge resumption set point. This approach is not recommended for larger systems, since power losses in the switching element are high. The electrical design of shunt type controller is shown in Figure 2.

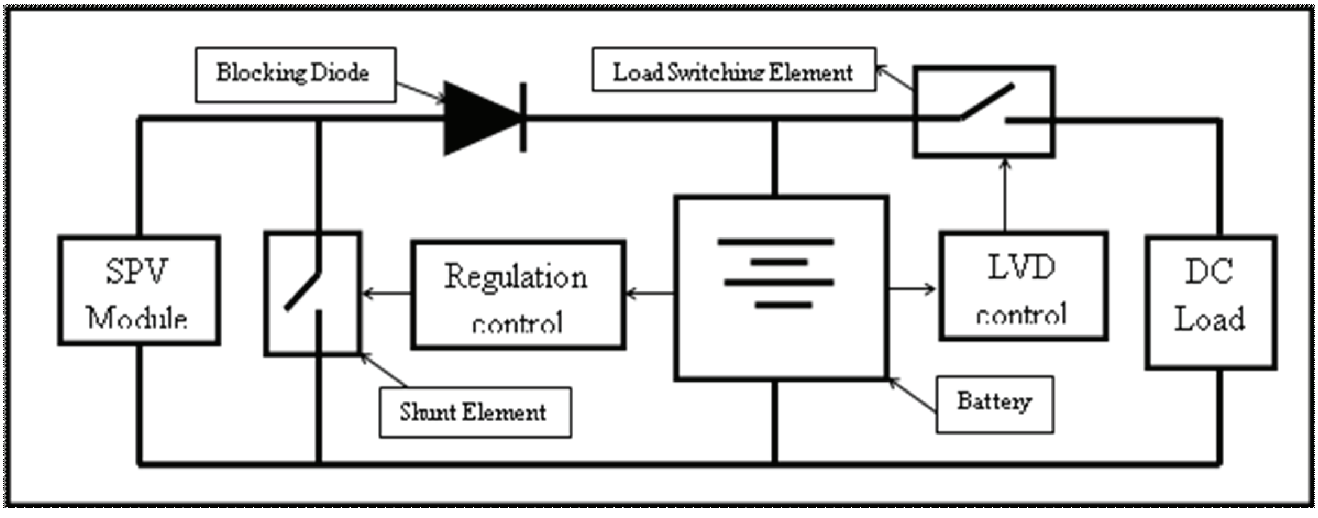

FIG. 2 SHUNT TYPE CHARGE CONTROLLER

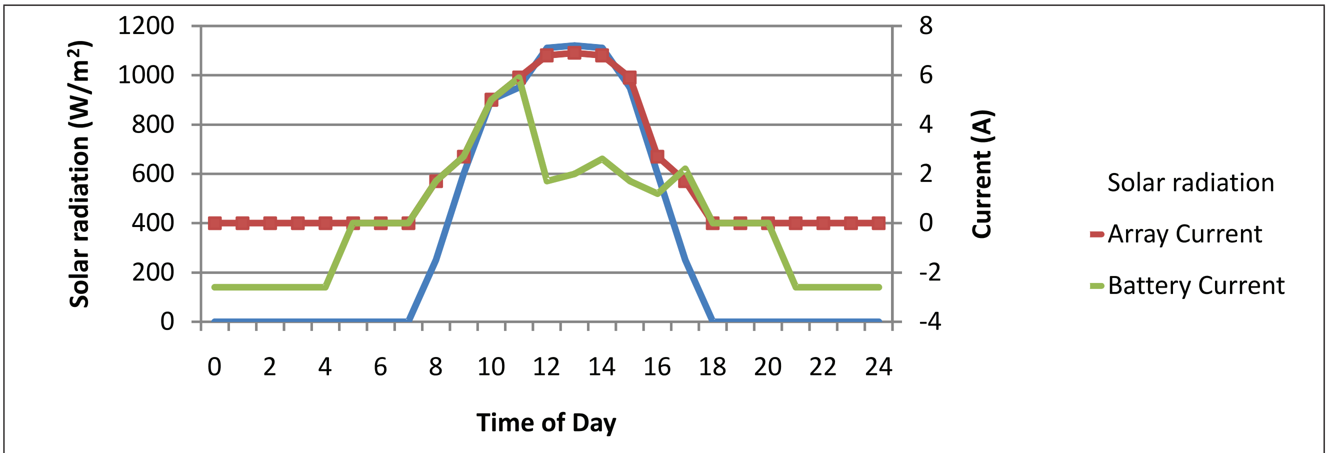

FIG. 3 SHUNT TYPE CHARGE CONTROLLER CURRENT CHARACTERISTICS

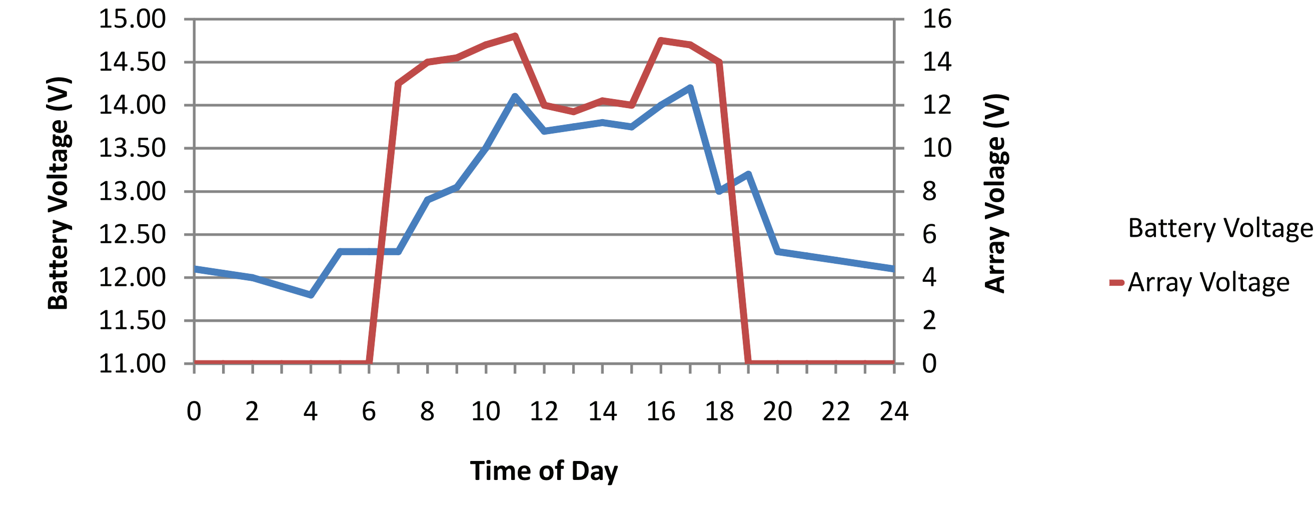

FIG. 4 SHUNT TYPE CHARGE CONTROLLER VOLTAGE CHARACTERISTICS

A shunt-interrupting charge controller suspends charging current to a battery system by short-circuiting the array through a shunt element inside the charge controller. This moves the array's operating point on the I-V curve to very near the short-circuit condition, limiting the power output. When the battery voltage falls, the controller reconnects the array to resume charging. The Figure 3 and 4 shows how the regulation takes place according to the solar irradiance.

At sunrise (07:00), the battery voltage begins to increase as the array current is fed into the battery. Near noon, the battery voltage reaches the voltage regulation set point and the controller begins regulating the array current. The battery current then decreases in a jagged manner that is characteristic of the interrupting (ON/OFF) algorithm. The shunt characteristic is illustrated by the fact that the array current continues to follow the same profile as the solar irradiance, while the array voltage decreases.

Shunt Linear (Zener diode): This method uses a control element to maintain the battery at the VR set point as it approaches full charge. By shunting power away from the battery in a linear manner, this provides constant voltage charge to the battery. In this controller, a zener diode with a reverse voltage rating equal to the VR set point is installed in parallel with the battery. When the battery voltage equals the diode voltage, diode conducts, shunting as much as current is necessary to keep the system on a constant voltage charge.

5.2 Series type Controllers

Series Interrupting (On/Off): This method terminates charging at the VR set point with an in-series element which open circuits the source. As with the shunt interrupting on/off controllers, charging is then resumed once battery voltage falls below the VRR set point. These controllers may, or may not, require a blocking diode depending on the switching element design.The electrical design of series type controller is shown in Figure 5.

A series-linear charge controller limits charging current to a battery system by gradually increasing the resistance of a series element. This limits current flow into the battery and maintains the battery at the voltage regulation set point. At sunrise (07:00), the battery voltage begins to increase as the array current charges the battery. Until about noon, the array current and the battery voltage increase steadily with increasing irradiance as the battery charges. During this period, the battery charge controller is not regulating and the array current is approximately the same as the battery current. Figure 6 and 7 shows how the regulation takes place in case of series type charge controllers.

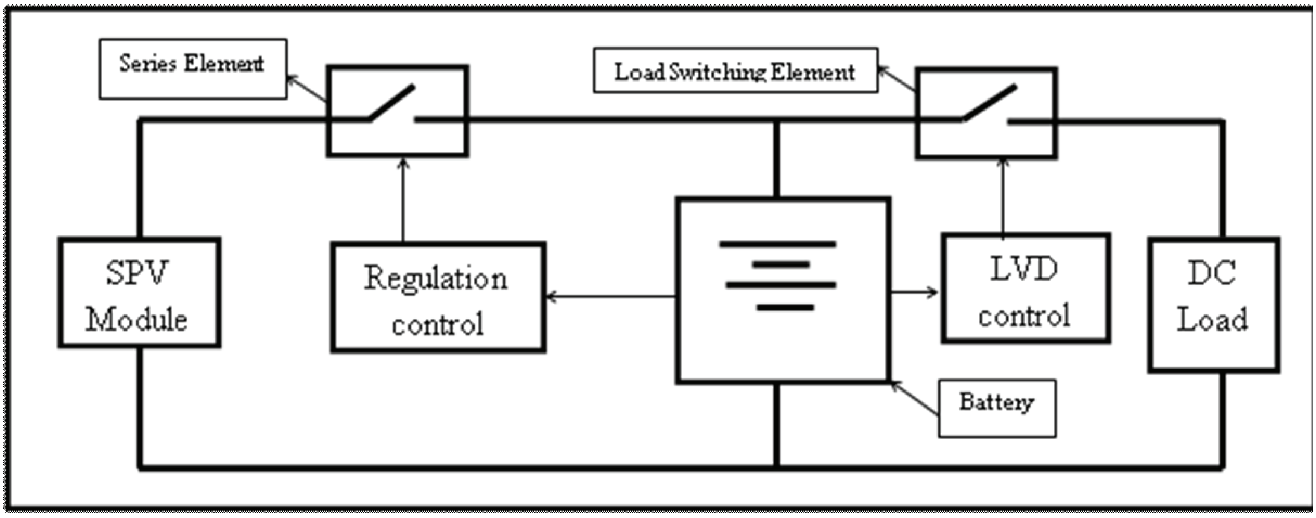

FIG. 5 SERIES TYPE CHARGE CONTROLLER

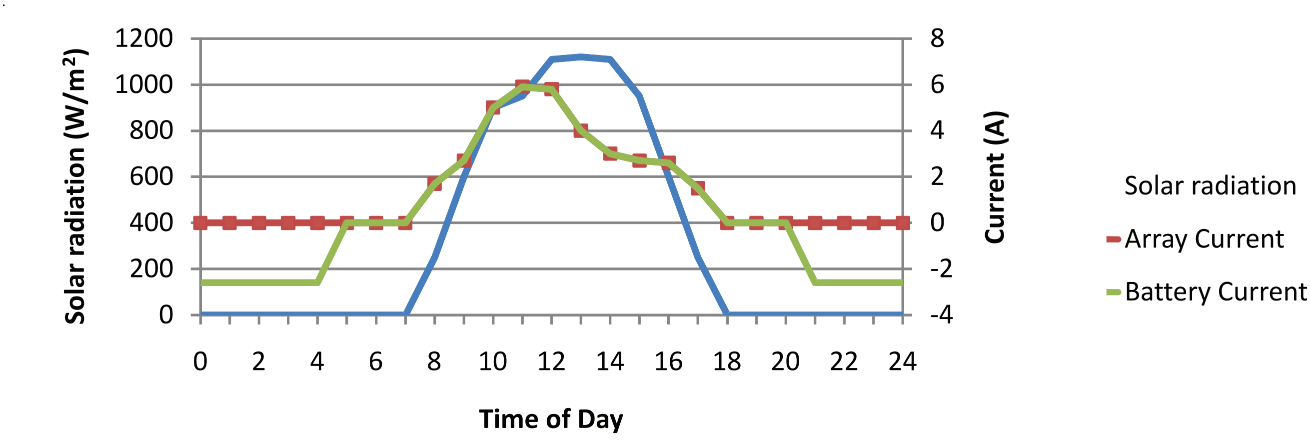

FIG. 6 SERIES TYPE CHARGE CONTROLLER CURRENT CHARACTERISTICS

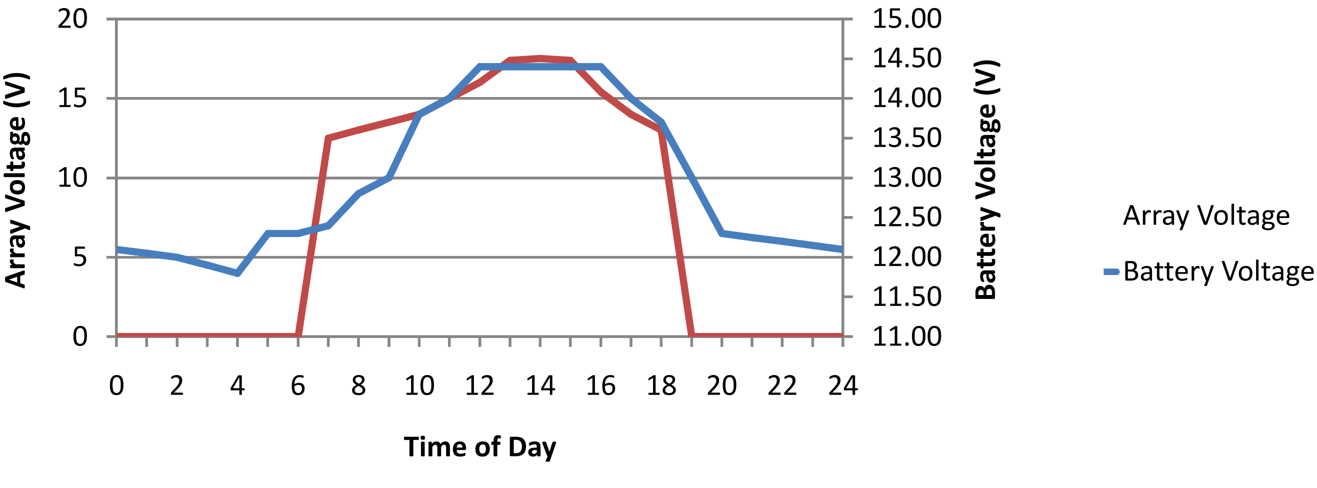

FIG. 7 SERIES TYPE CHARGE CONTROLLER VOLTAGE CHARACTERISTICS

Series Linear: This method applies a constant voltage to the battery as it approaches the full charge VR set point by using a series control element which acts like a variable resistor. This element dissipates the balance of the power that is not used to charge the battery.

Series Interrupting, 2-step, Constant-Current Design: This type of controller is similar to the series interrupting type, however when the voltage regulation set point is reached, instead of totally interrupting the source current, limited constant current remains applied to the battery. This trickle charging continues either for a pre-set period of time, or until the voltage drops to the array reconnect voltage due to load demand. Then full source current is allowed to flow, and the cycle repeats.

5.3 Pulse Width Modulation (PWM)

This method uses solid state switches to apply pulses of current at a reasonably high frequency, but with a varying duty cycle, such that the battery receives a constant voltage charge from the array. Although this method is similar to the series linear and shunt linear controller in function, power dissipation is reduced with the PWM topology compared to series linear control.

6.0 HYBRID SYSTEM CONTROL

Hybrid systems incorporate more than one type of electric generator. In addition to photovoltaic, they may include wind turbines, micro-hydro generators, thermo-electric generators and fossil fuel powered generators. When hybrid systems rely on renewable energy alone, they generally have no control over power generation, they cannot influence the wind, the sun or the rains. For these systems, charge and discharge control is largely the same as in systems with photovoltaicgenerators only. On the other hand, when hybrid systems contain generators which can supply power on demand, the situation is very different. When renewable alone are unable to meet the load, the fossil fuel-powered generators, or “gensets” can be switched on, if there are no equipment failures, the loss-of-load probability falls to zero. Figure 8 shows the Hybrid system.

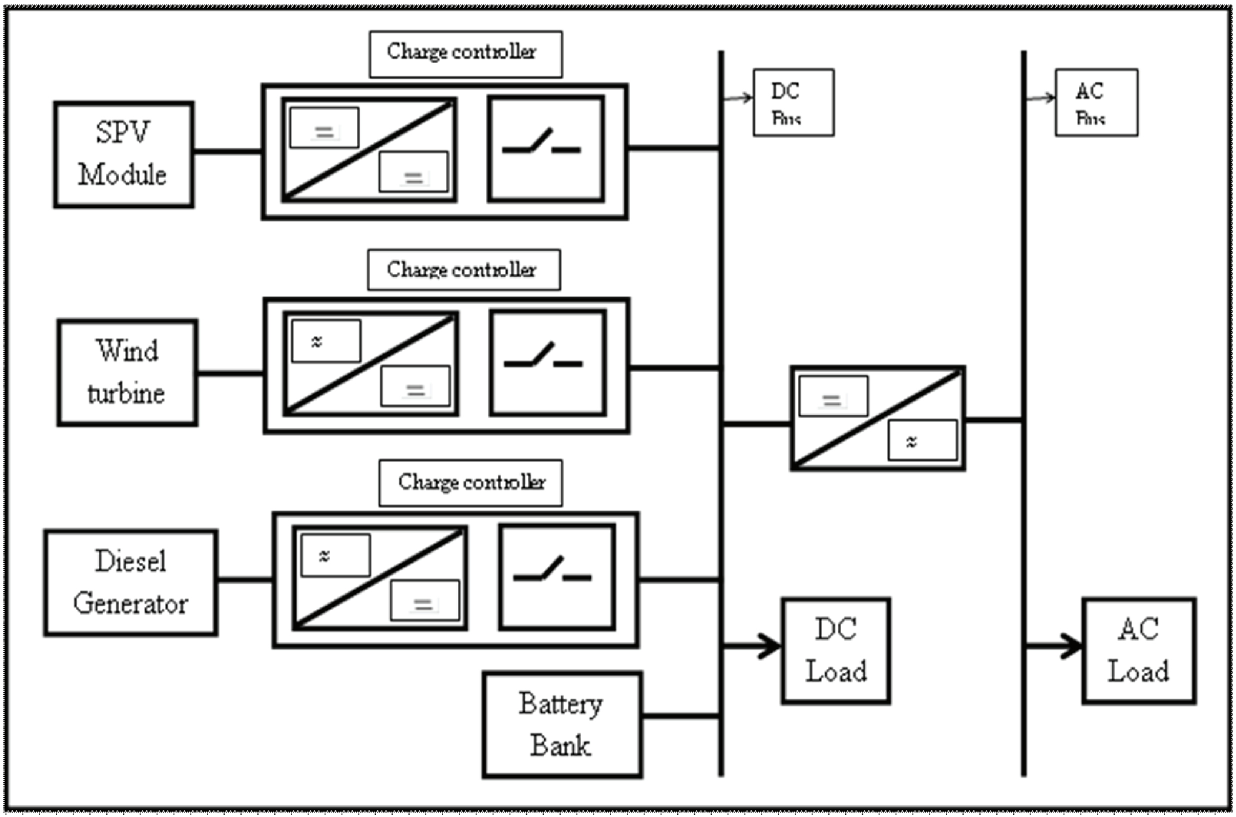

FIG 8: HYBRID POWER GENERATING SYSTEM

In hybrid systems, one objective of charge and discharge control is to maximize the battery lifetime, just as in stand-alone PV systems. When power on demand is added, a second objective is the minimization of the cost of genset fuel and maintenance.

6.1 Control of a Hybrid system

In hybrid system control refers to three different aspects of system operation:

1. Dynamic control: maintaining the characteristics of the output waveform at desired levels regardless of the load and power being produced by the different generators.
2. Charge control: regulating the flow of current to the battery, especially at the end of charge.
3. Dispatch: for systems with power on demand, determining when the genset should be turned on and off.

In many ways, charge control for hybrid systems is very similar to charge control for photovoltaic systems. However, the four important differences do exist. First, hybrid systems tend to have relatively small battery banks which are cycled more than typical photovoltaic battery banks. This increases the danger of stratification if the batteries are not regularly equalized, and generally ensures that it is the cycle life that limits the battery lifetime. Second, when power is available on demand, many of the unexpected changes associated with charging from an intermittent power sources are eliminated, simplifying charge control. Third, hybrid systems are typically used for bigger loads than photovoltaic systems. This means that the controller can be more expensive, and have more functionality, without significantly increasing the system cost. Fourth, charge currents can be quite high, especially if the genset is oversized.

While the battery manufacturers are often unable to recommend appropriate charge control methods for photovoltaic systems, they are usually quite familiar with the regular cycling operation of their battery. Thus, they are generally able to recommend appropriate charge methods and frequency of equalization for their batteries used in hybrid systems. Furthermore, hybrid system controllers are often sufficiently sophisticated that these recommended practices can be followed without much trouble.

7.0 CONCLUSIONS

Non-optimal charging of the battery will lead to the high maintenance cost because it will reduce the life span of the battery by 40%. So the best way to increase the efficiency and performance of the battery by 35% is the optimal charging. Charge controllers will handle this task of optimal charging to improve the performance of the battery.

Series and shunt type charge controllers are not more efficient than PWM and MPPT charge controllers, but the series and shunt type charge controllers are simple in design and cost is less whereas PWM and MPPT charge controllers are complex in design and expensive.

In hybrid power generating system, if there are multiple sources like solar and wind power generating system each can have different charge controllers to handle charge regulation or the hybrid system can have single charge controller. The design of the single charge controller is complex. Hence multiple charge controllers are recommended. The multiple charge controllers will be able to optimize the entire hybrid system instead of a single system.

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